Wireless Sensor Networks

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Audio/Video recordings of this lecture are available at:

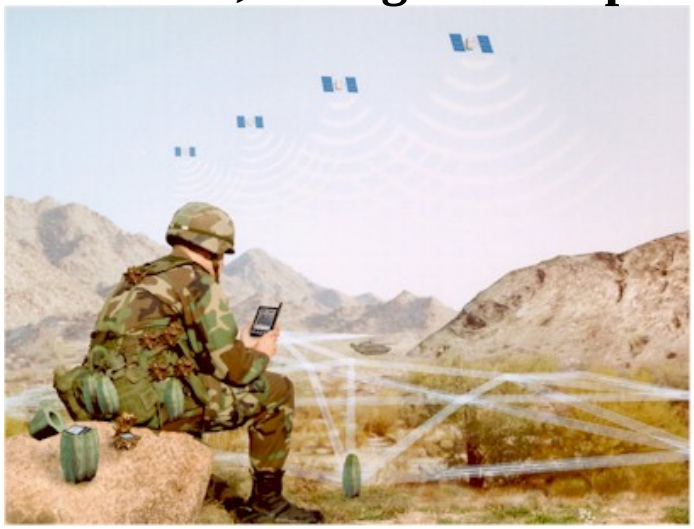
http://www.cse.wustl.edu/~jain/cse574-10/

Overview

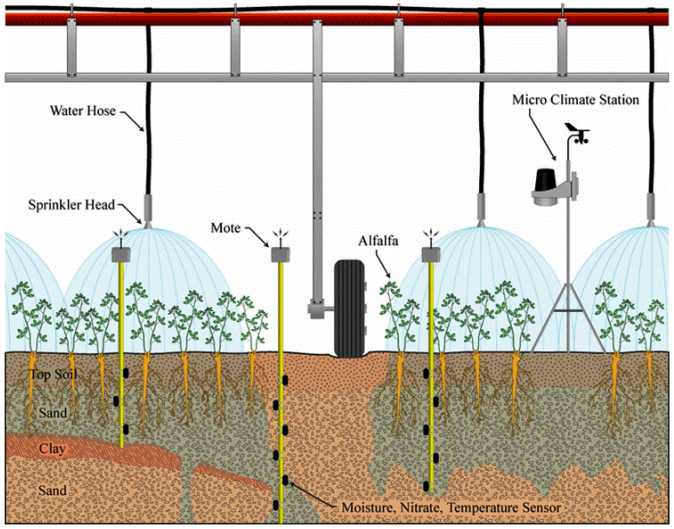
- Sensor Applications
- IEEE 802.15.4-2006
- 6LowPAN
- WirelessHART
- Research Issues

Sensor Applications

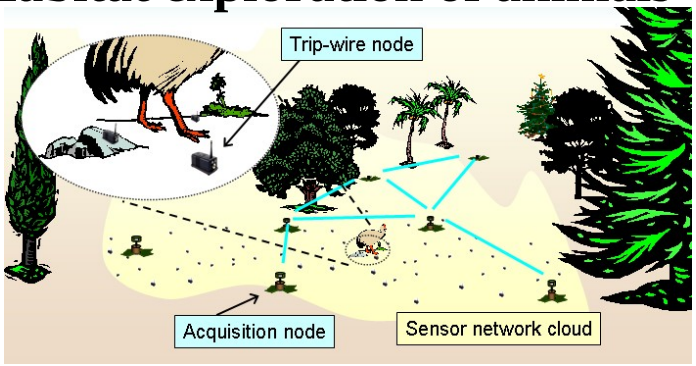
Battlefield Surveillance
Chemical, Biological Weapons



Crops and Agriculture
Forest Fires and Flood Detection



Habitat exploration of animals



Patient heart rate, blood pressure

Sensor (vs. Ad-Hoc)

- Large scale
- Batteries may not be replaceable
- May not have global identifiers
- Queries may be data centric rather than address centric:
  - Who's temperature is more than 95 degree vs. What is your temperature?

  $\Rightarrow$ Geographical routing, Data fusion, Data aggregation

IEEE 802.15.4-2006

- Low-Rate Wireless Personal Area Network
- Physical layer used in ZigBee, WirelessHART, MiWi which add upper layers
- 10 m reach at 250 kbps (20/40/100 kbps versions)
- Three Frequency Bands:
  - 868.0-868.6 MHz in Europe
  - 902-928 Mhz in North America
  - 2400-2383.5 MHs worldwide
- Uses Direct Sequence Spread Spectrum (DSS)
- BPSK or QPSK modulation
- IEEE 802.15.4a-2007 added ultra-wideband, and chirp spread spectrum
- IEEE 802.15.4c-2009, IEEE 802.15.4d-2009 adde more PHYs and modulations

IEEE 802.15.4 Topologies

- Star, Peer-to-peer, Structured star
- Full function and reduced function devices

Two modes:

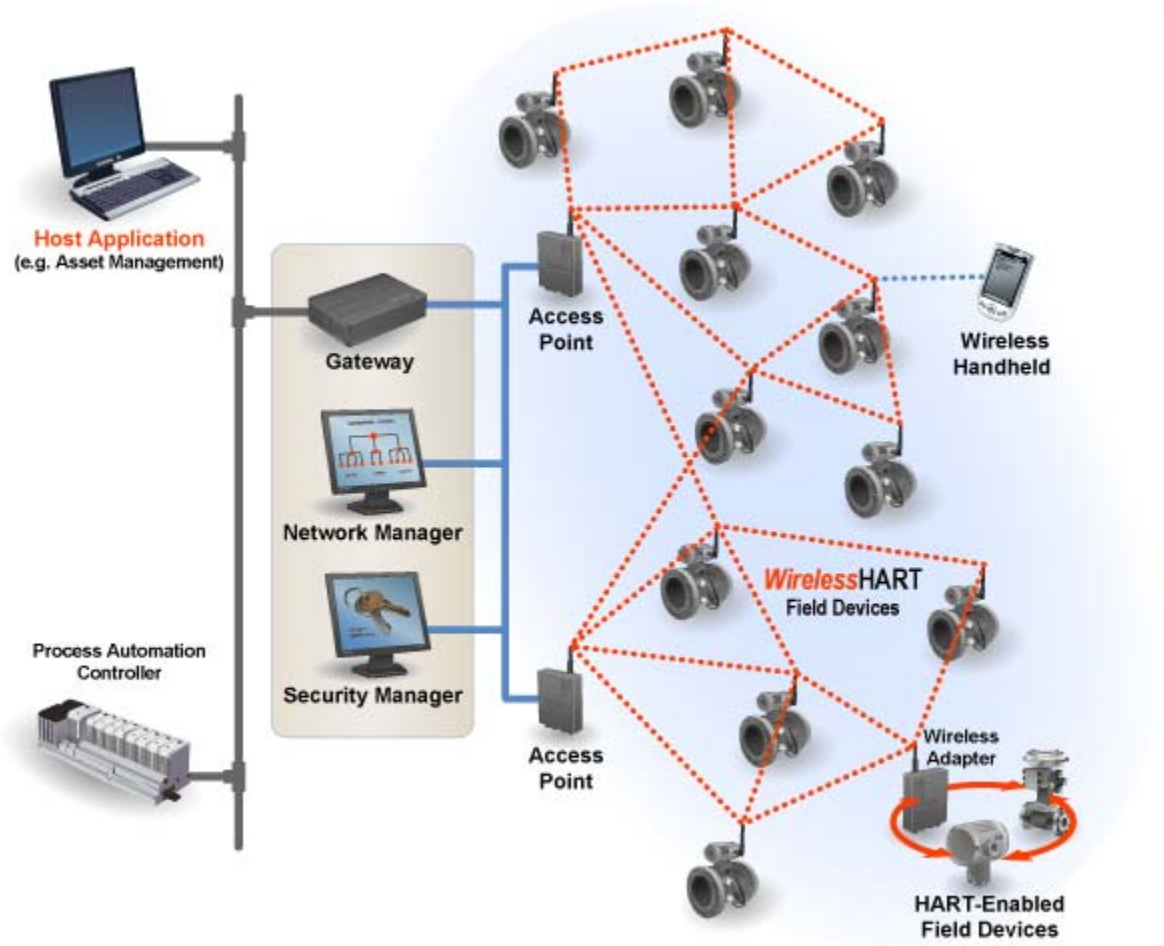
- With Beacon: Coordinator sends start beacon and stop beacon to indicate active time.
  - The time is slotted. Slotted CSMA/CA. Transmissions end at second beacon.
- Without Beacon: Unslotted CSMA/CA protcol with random exponential backoff

Ref: http://en.wikipedia.org/wiki/802.15.4

6LowPAN

- IETF Working Group: IPv6 over Lower Power Wireless Personal Area Networks (IPv6 over IEEE 802.15.4)
- IEEE 802.15.4 allows 127 byte packets minus 25 byte framing overhead minus 21 bytes for AES security = 81 byte IP packet
- IPv6 requires a min transmission unit (MTU) of 1280 bytes.
  - Need to compress IPv6 headers.
  - 64-bit Extended IEEE 802 addresses or 16-bit local IDs are used
- 6LowPAN defined an adoption layer that compresses IPv6 headers and allows PANs to be connected to regular IPv6 networks.
- REF: RFC 4944, Transmission of IPv6 Packets over IEEE 802.15.4 Networks
- RFC 4919: IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs):Overview, Assumptions, Problem Statement, and Goals

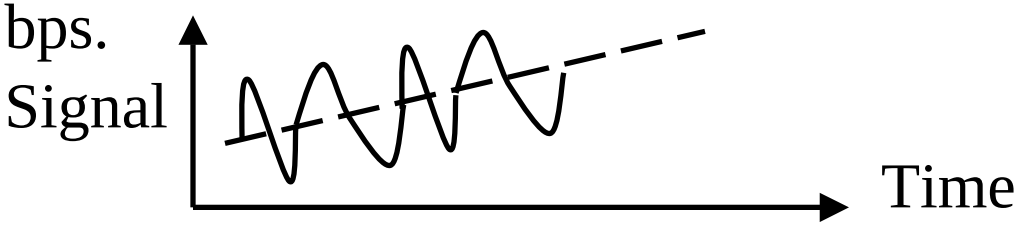
WirelessHART



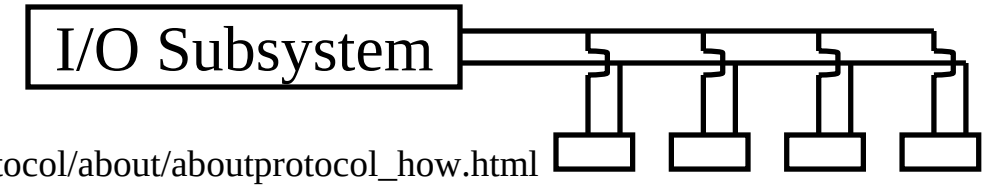
- A commonly used sensor network protocol stack

HART

- Highway Addressable Remote Transducer
- Communication between smart devices and monitoring systems
- 4-20 mA current loop is a commonly used analog measurement technique
- Low level frequency shift keying (FSK) over 4-20 mA analog signal. 1200 bps.



- Master/slave protocol with two masters (primary, secondary)
- Point-to-point or multi-drop configuration



- Full 7 layer stack
- Ref:http://www.hartcomm.org/protocol/about/aboutprotocol_how.html

HART Protocols

- Full stack: Layer 1, 2, 3, 4, and 7
- Layer 1: FSK
- Layer 2: Master-Slave. Upto 15 devices in a multi-drop line
- Layer 3: Routing, security
- Layer 4: end-to-end
- layer 7: Commands, response, data types, and status
- Device Description: Like a MIB
  - Specifies the functions and features of a device
  - Device description language
  - Allows manufacturer specific features
  - Can be compiled to create management screens for devices

Ref:http://www.hartcomm.org/protocol/about/aboutprotocol_specs.html
http://www.hartcomm.org/hcf/documents/documents_spec_list.html

WirelessHART

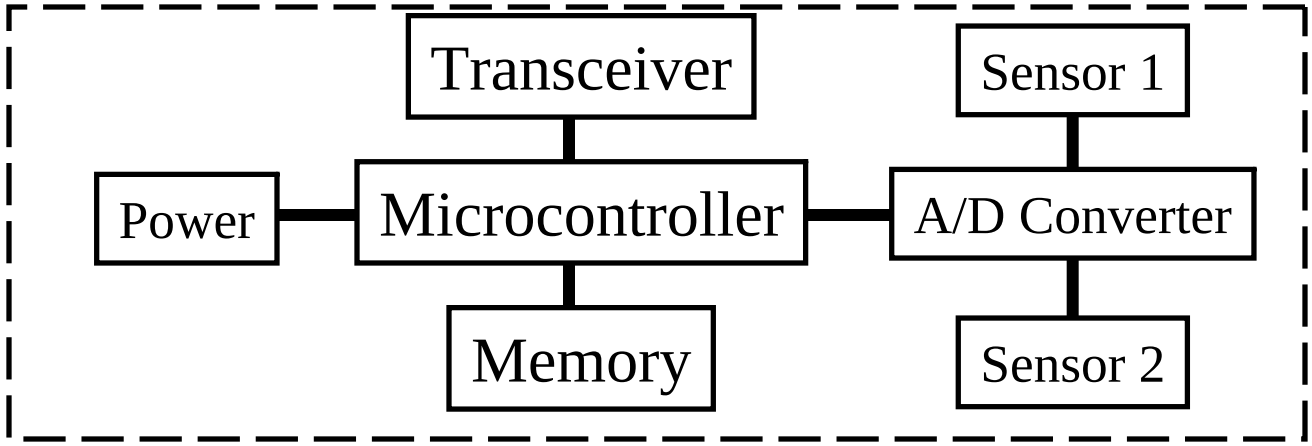
- Extension of HART to Wireless
- Supports star and mesh topologies
- Self-organizing and self-healing
- Uses IEEE 802.15.4-2006 radios in 2.4GHz
- Frequency hopping with blacklisting to avoid used channels
- 128-bit AES encryption
- Uses multi-path routing. Messages alternate paths to ensure secondary paths are up.

Ref: http://www.hartcomm.org/protocol/wihart/wireless_how_it_works.html
http://www.hartcomm.org/protocol/training/training_resources_wihart.html

WirelessHART Field Devices

- WirelessHART adapter or builtin
- Gateways: Connect to the backbone network
- Network Manager: Manages routes, monitors health (can be integrated in to gateways or hosts)
- Security Manager: Contains list of authorized devices. Distributes security keys.
- Repeater: Extends the range.
- Adapter: Attaches to devices without wirelessHART

Sensor Node



- A device with sensors, networking hardware, and power
- Small size ⇒ Dust or **Motes**
  DARPA funded Smart Dust project
  (Dust Network, Inc. is a Silicon valley startup for Motes)
- **TinyOS** is a public domain operating system designed for sensor nodes

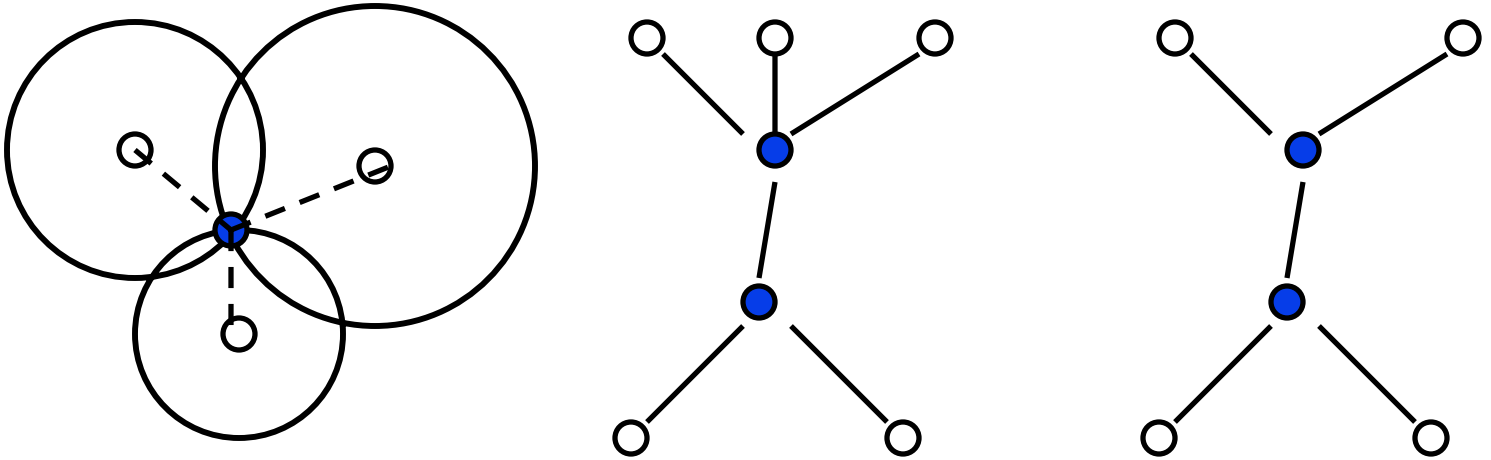
Ref: http://en.wikipedia.org/wiki/Motes
http://en.wikipedia.org/wiki/Smartdust
http://en.wikipedia.org/wiki/TinyOS
http://en.wikipedia.org/wiki/Dust_Networks

Research Issues

1. Location Discovery
2. Quality of a Sensor Network
3. Time Synchronization
4. Transport Layer Issues
5. Real-Time Communication

Location Discovery

- Location Stamp on data
- **Indoor Localization**: Reference nodes in each location
- **Atomic Multi-Lateration**: Need 3 references
- **Iterative Multi-Lateration**: Nodes with known location become references for others
- **Collaborative Multi-Lateration**: Use quadratic equations

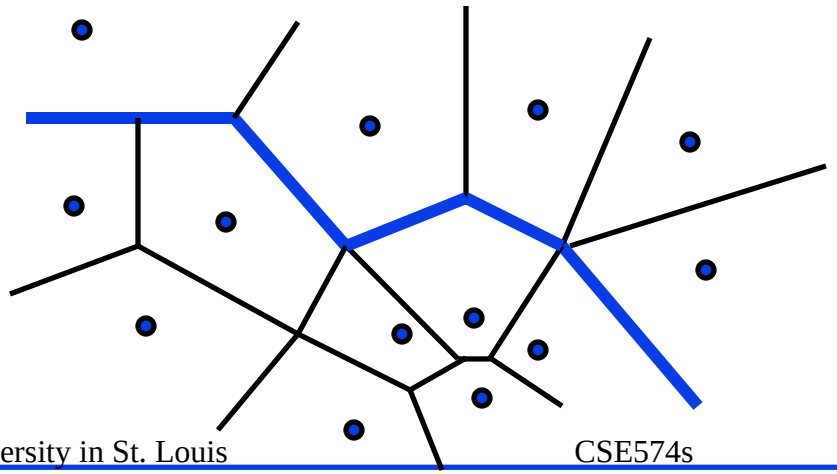


Global Positioning System (GPS)

- US Department of Defense $12B
- Man made stars
- 24 Satellites and their ground stations
- Triangulation
- Measures travel time of radio signal ⇒ Distance
- Satellites broadcast current time and their location using a Direct Sequence Code
- 1023 chips per bit
- 3 satellites give (x, y, z)
- 4 satellites give (x, y, z, t)
- Correct for any delays experienced through the atmosphere
- http://www.edu-observatory.org/gps/tutorials.html

Quality of a Sensor Network

- Quality = Coverage + Exposure
- **Exposure**: Ability to observe a target.
  Ability decreases with the distance from the target
- **Coverage**: How well is the region covered with sensors
  Find the least covered path that could be followed by enemy
- **Voronoi Diagram**: Cost = Distance from nearest sensor
  Find the maximum cost path.
- Opposite Problem: Find the best covered path



Time Synchronization

- GPS not accessible inside buildings, under water.
- Send a time stamp to neighbor
- One-way Delay = Send Time (Preparing the message) + Access Time (media access) + propagation time + receive time (processing at receiver)
- Best to timestamp the message at the PHY layer of the receiver
- **Post Facto Synchronization**:
  - Announce time along with the event.
  - Everyone else synchronizes to it
  - Leader periodically sends sync messages, which are flooded
  - Distributed election of the leader based on a random number
- Resynchronization: Upon merger of partitions. Better to advance the clock

Transport Layer Issues

- Reliable transmission of data from sources to sinks

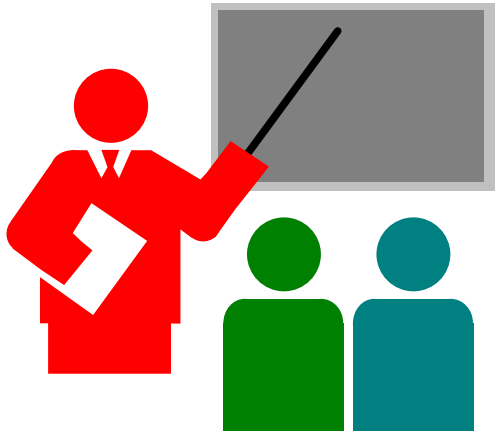
PSFQ:

- Ask previous hop to retransmit if error $\Rightarrow$ Fetch
- Forward to next hops $\Rightarrow$ Pump
- Pump slowly and fetch quickly (PSFQ)
  $\Rightarrow$ Minimize storage, maximize reliability
- Farthest node sends a report of delivery status to the source.
- Intermediate nodes append their status to the same message.

Real-Time Communication

- SPEED: Geographical routing ⇒ Send packets to neighbors in the direction of the destination
- Nodes send delay feedback backwards as packets are forwarded
- Nodes can also send a backpressure message if delay too high
- Select the neighbor with least delay
- If no neighbor can meet the delay constraint, the packet is dropped
- No node close to the destination ⇒ Void
- Void avoidance ⇒ Issue a back-pressure with infinite delay
  ⇒ Search for alternate paths

Summary



- IEEE 802.15.4 PHY layer is designed for sensor networks
- ZigBEE and WirelessHART are two common protocol stacks
- Location Discovery is by triangulation or multi-lateration
- Quality of a Sensor Net is measured by coverage and exposure
- Time Synchronization by exchanging timestamps
- Transport: Pump slowly and fetch quickly increases reliability
- Real-Time Communication using deadline based forwarding

Related Wikipedia Articles

- http://en.wikipedia.org/wiki/Category:Wireless_sensor_network
- http://en.wikipedia.org/wiki/Wireless_sensor_network
- http://en.wikipedia.org/wiki/Body_sensor_network
- http://en.wikipedia.org/wiki/Intelligent_sensor
- http://en.wikipedia.org/wiki/Key_distribution_in_wireless_sensor_networks
- http://en.wikipedia.org/wiki/Location_estimation_in_sensor_networks
- http://en.wikipedia.org/wiki/Semantic_Sensor_Web
- http://en.wikipedia.org/wiki/SensorML
- http://en.wikipedia.org/wiki/Sensor_Web

Related Wikipedia Articles (Cont)

- http://en.wikipedia.org/wiki/Sensor_grid
- http://en.wikipedia.org/wiki/Sensor_node
- http://en.wikipedia.org/wiki/Smartdust
- http://en.wikipedia.org/wiki/TinyOS
- http://en.wikipedia.org/wiki/Virtual_Sensor_Networks
- http://en.wikipedia.org/wiki/Visual_sensor_network
- http://en.wikipedia.org/wiki/WirelessHART
- http://en.wikipedia.org/wiki/Secure_Data_Aggregation_in_WSN
- http://en.wikipedia.org/wiki/ZigBee
- http://en.wikipedia.org/wiki/Dust_Networks

Reading Assignment

- Read Chapter 12 of Murthy and Manoj

Homework

A node X receives three beacons from nodes A, B, and C at (0, 0, 0), (2, 6, 0), and (3, 4, 0), respectively. From the received signal strengths, it determines the distances to A, B, and C to be $\sqrt{26}$, $\sqrt{6}$, and $\sqrt{11}$, respectively. Find the coordinates of X.

List of Acronyms

- BS — Base Station
- GPS — Global Positioning System
- ID — Identifier
- LEAP — Localized Encryption and Authentication Protocol
- MAC — Media Access Control
- PEGASIS — Power-Efficient Gathering for Sensor Information Systems
- PHY — Physical Layer
- PSFQ — Pump slowly and fetch quickly
- SPEED — Speed (Not an acronym)
- TDMA — Time Division Multiple Access